PRINCE WILLIAM SOUND 1988 HERRING BIOMASS PROJECTION

By

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INTRODUCTION

The purpose of this report is to present a Prince William Sound herring biomass projection for the 1988 spring spawning migration.

METHODS

The 1988 Prince William Sound herring total run biomass projection is based on the 1987 age-specific escapement biomass, adjusted for growth and mortality, and recruitment. During the 1987 spawning migration, the age structure of the spawning biomass changed from a dominance of older to younger-aged herring during the spawning migration. Consequently, due to this temporal age-class variability, an age-specific biomass distribution schedule based on the mean AWL age-class structure was inappropriate. Therefore, in order to more precisely estimate the contribution of each age-class to the total run biomass particular daily biomass estimates were associated with individual, or sets of herring age, weight and length (AWL) samples obtained from assumed non-selective gear types. Non-selective gear types were assumed to include purse seines and beach seines. The 1987 herring AWL sample summaries are found in Sandone et al. (*In press*).

Daily biomass estimates were partitioned by time and area into strata (A, B, C, and D) (Figure 1). Strata definitions were based upon observed changes in the daily area-specific biomass estimates and/or age-class composition structure reflected by associated AWL samples. The stratum biomass estimate was also expressed as a percent of the total run biomass (Figure 1), so that adjustments to the total run biomass could be easily incorporated into the stratification procedure.

In order to determine the age structure of the biomass within each strata, the estimated strata biomass was distributed by the mean age contribution (percent by weight) of the AWL samples collected within the stratum (Appendix A). The estimated total herring biomass was determined by summing the contribution of each age (tons) across all strata. The 1987 age-specific escapement biomass was calculated simply by subtracting the total commercial harvest from the total run biomass for each age. The age distribution of the various commercial harvests (Appendix B) was based on the AWL samples obtained from each fishery harvest.

Age-specific instantaneous natural mortality rates (M) are necessary in order to determine the natural mortality of the escapement biomass. Direct estimates of natural mortality rates, however, were not available for Prince William Sound herring. Therefore, a range of age-specific mortality rates were employed in the projection calculations. These natural mortality rates represent the extreme and mean rates used by Funk and Sandone (*In press*) in their assessment of Prince William Sound herring using cohort analysis. These age-specific rate schedules are identified by the mortality rate assigned to age-8 herring (age interval 8-9). The mortality rate schedule

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used in this report were: M at age-8 = 0.300, 0.450, and 0.600.

Age-specific instantaneous growth rates (G) were based on herring weight at age calculated from the Prince William Sound herring weight-age relationship (Funk and Sandone *In press*). The availability (A) of a cohort-at-age (Funk and Sandone *In press*) was used to estimate that portion of the total cohort biomass which was expected to contribute to the spawning biomass. Availability was defined as that portion of the total cohort which was on the spawning grounds during the spring harvest period.

The 1987 escapement biomass was projected forward in time using model:

$$B_{1988,t+1} = E_{1987,t} * e^{(G-M)} * A_{1988,t+1} / A_{1987,t}$$

where:
$B_{1988,t+1}$ = 1988 projected biomass for age t+1
$E_{1987,t}$ = 1987 escapement biomass for age t,
$A_{1988,t+1}$ = Availability in 1988 of age t+1, and
$A_{1987,t}$ = Availability in 1987 of age t.

The total 1988 projected biomass was determined by summing the age-specific biomass projections. A minimal projected biomass of age-3 herring for the 1988 spawning migration was estimated by substituting the relationship between availability of age-4 to age-3 herring for the unavailable age-3 to age-2 availability relationship. The availability of age-2 herring was unavailable, but considered less than the availability of age-3 herring. Since the actual age-4 to age-3 herring availability relationship was most likely smaller than the age-3 to age-2 relationship, the projection of age-3 herring was considered a minimal projection estimate.

The combined strata estimated herring biomass of 27,020 tons (Figure 1) was slightly larger than the peak daily estimate of 24,090 tons (Brady 1988). However, aerial assessment of the herring biomass probably documents only a portion of the total herring biomass. Therefore, based on a combination of factors, the 1987 spawning biomass was assessed at between 40-45,000 tons (James Brady, Alaska Department of Fish and Game, Cordova, personal communication). Due to the difference in observed versus assessed biomass, a 1988 biomass projection was calculated for the escapement biomass resulting from a 1987 total run biomass of 27,020 and 40,000 tons.

RESULTS

The 1987 escapement biomass based on a total run biomass of 27,020 and 40,000 tons was 20,837 and 33,817 tons, respectively. The six different projection scenarios, which resulted from the employment of three different natural mortality rate schedules (M at age-8 = 0.300, 0.450, and 0.600) and two different 1987 escapement biomass estimates, provided a range of projected 1988 total run estimates of from 23,840 to 51,112 tons (Appendix C). However, the scenarios based on the mid-value natural mortality rate (M at age-8 =

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0.450) yielded 1988 herring biomass projections which were very similar to the 1987 total run biomass. Using this mid-value natural mortality rate schedule, the projected 1988 total run biomass based on a 1987 total biomass run of 27,020 and 40,000 tons was 27,698 and 43,992 tons, respectively (Table 1 and 2). However, regardless of the scenario used, the age 4 (1984 year class) herring are expected to dominate the 1988 total run biomass. This strong year class is projected to contribute between 65% and 67% by number to the total run herring biomass. The previously dominant 1980 (age 8) and 1981 (age 7) year classes are expected to contribute no more than 8% and 13%, respectively, to the 1988 total run biomass.

LITERATURE CITED

Brady, J. A. 1987. Distribution, timing and relative biomass indices for Pacific herring as determined by aerial surveys in Prince William Sound 1978 to 1987. Prince William Sound Data Report No. 87-14. Alaska Department of Fish and Game, Commercial Fisheries Division, Juneau.

Funk, F. C., and G. J. Sandone. *In press*. Stock assessment of Prince William Sound Herring 1973-1987, using cohort analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

Sandone, G. J., S. Sharr, and J. A. Brady. *In press*. Prince William Sound commercial Pacific herring harvest summary, data presentation and analysis 1984-1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

Table 1. Prince William Sound District year-class composition of the 1987 Pacific herring harvest, escapement, and total run biomass and the 1988 projected biomass.

Natural mortality rate (M) at age 8 = 0.450; Total 1987 herring biomass = 27,020 tons.

Year Class	Age Class	1987 Harvest (tons)				1987 Escapement (tons)	1987 Total Run			
		Purse S.	Gill Net	Pound	Total		Biomass (tons)	No.of Fish (* 1,000)	% by Wt.	% by No.
1986	1	0	0	0	0	0	0	0	0.0	0.0
1985	2	1	0	2	4	26	30	493	0.1	0.2
1984	3	434	0	436	869	7,101	7,970	101,747	29.5	45.2
1983	4	297	0	59	355	1,721	2,076	20,032	7.7	8.9
1982	5	432	13	40	485	1,520	2,005	14,970	7.4	6.6
1981	6	1,653	192	111	1,955	4,858	6,813	43,152	25.2	19.2
1980	7	1,450	165	67	1,682	3,833	5,515	31,694	20.4	14.1
1979	8	204	59	14	278	785	1,063	5,680	3.9	2.5
1978	9	147	32	9	188	364	552	2,731	2.0	1.2
1977	10	152	49	9	209	356	566	2,650	2.1	1.2
1976	11	108	27	7	142	255	396	1,810	1.5	0.8
1975	12	9	6	1	16	18	33	163	0.1	0.1
1974	13+	0	0	0	0	0	0	0	0.0	0.0
Total		4,886	543	754	6,183	20,837	27,020	225,122	100.0	100.0

Year Class	Age Class	1988 PWS Projected Herring Biomass			
		Biomass (tons)	No.of Fish (* 1,000)	% by Wt.	% by No.
1986	2	0	0	0.0	0.0
1985	3	68	783	0.2	0.4
1984	4	16,104	141,921	58.1	66.8
1983	5	2,092	15,344	7.6	7.2
1982	6	1,405	9,043	5.1	4.3
1981	7	4,299	25,195	15.5	11.9
1980	8	2,849	15,594	10.3	7.3
1979	9	526	2,741	1.9	1.3
1978	10	194	973	0.7	0.5
1977	11	121	590	0.4	0.3
1976	12	39	189	0.1	0.1
1975	13+	1	4	0.0	0.0
Total		27,698	212,376	100.0	100.0

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Table 2. Prince William Sound District year-class composition of the 1987 Pacific herring harvest, escapement, and total run biomass and the 1988 projected biomass.
Natural mortality rate (M) at age 8 = 0.450; Total 1987 herring biomass = 40,000 tons.

| | | 1987 Harvest (tons) | | | | 1987 Escapement | 1987 Total Run | | | | 1988 PWS Projected Herring Biomass | | | | | |
Year Class	Age Class	Purse S.	Gill Net	Pound	Total	(tons)	Biomass (tons)	No.of Fish (* 1,000)	% by Wt.	% by No.	Age Class	Year Class	Biomass (tons)	(* 1,000)	% by Wt.	% by No.
1986	1	0	0	0	0	0	0	0	0.0	0.0	2	1986	0	0	0.0	0.0
1985	2	1	0	2	4	41	45	730	0.1	0.2	3	1985	105	1,210	0.2	0.4
1984	3	434	0	436	869	10,930	11,799	150,624	29.5	45.2	4	1984	24,787	218,445	56.3	65.2
1983	4	297	13	59	355	2,718	3,073	29,656	7.7	8.9	5	1983	3,304	24,237	7.5	7.2
1982	5	432	40	40	485	2,484	2,969	22,161	7.4	6.6	6	1982	2,295	14,774	5.2	4.4
1981	6	1,653	192	111	1,955	8,131	10,086	63,882	25.2	19.2	7	1981	7,195	42,170	16.4	12.6
1980	7	1,450	165	67	1,682	6,482	8,164	46,919	20.4	14.1	8	1980	4,818	26,372	11.0	7.9
1979	8	204	59	14	278	1,296	1,574	8,409	3.9	2.5	9	1979	869	4,523	2.0	1.4
1978	9	147	32	9	188	629	817	4,043	2.0	1.2	10	1978	335	1,681	0.8	0.5
1977	10	152	49	9	209	628	837	3,924	2.1	1.2	11	1977	213	1,040	0.5	0.3
1976	11	108	27	7	142	445	587	2,680	1.5	0.8	12	1976	69	329	0.2	0.1
1975	12	9	6	1	16	34	50	241	0.1	0.1	13+	1975	1	7	0.0	0.0
1974	13+	0	0	0	0	0	0	0	0.0	0.0						
Total		4,886	543	754	6,183	33,817	40,000	333,268	100.0	100.0			43,992	334,789	100.0	100.0

Stratum	Biomass (tons)	%
A	14,960	55.4
B	2,900	10.7
C	2,340	8.7
D	6,820	25.2
Total	27,020	100.0

STRATUM A

STRATUM B

STRATUM C

STRATUM D

* Indicates days that surveys were not flown due to poor weather.

** AWL sample collected from corresponding area and date.

(○) Biomass included in stratum biomass total.

Figure 1. Pacific herring biomass stratification schedule, Prince William Sound, 1987.

APPENDICES

Appendix A.1. Prince William Sound herring biomass distribution by age and year class, Stratum A, 1987.

Stratum A

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Biomass (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	1	0.0	73	73	0.0	3	31
1984	3	415	13.5	81	33,795	7.8	1,173	13,070
1983	4	250	8.1	107	26,836	6.2	932	7,873
1982	5	318	10.3	127	40,537	9.4	1,407	10,015
1981	6	1,015	32.9	146	148,155	34.4	5,143	31,965
1980	7	764	24.8	161	123,132	28.6	4,275	24,061
1979	8	141	4.6	170	24,035	5.6	834	4,441
1978	9	65	2.1	186	12,099	2.8	420	2,047
1977	10	66	2.1	192	12,702	2.9	441	2,079
1976	11	44	1.4	200	8,809	2.0	306	1,386
1975	12	4	0.1	192	767	0.2	27	126
1974	13+	0	0.0		0	0.0	0	0
	Total	3,083	100.0	140	430,940	100.0	14,960	97,093

Appendix A.2. Prince William Sound herring biomass distribution by age and year class, Stratum B, 1987.

Stratum B

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Biomass (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	0	0.0	0	0	0.0	0	0
1984	3	190	32.4	72	13,680	19.1	554	6,983
1983	4	42	7.2	99	4,158	5.8	168	1,544
1982	5	51	8.7	119	6,069	8.5	246	1,874
1981	6	157	26.8	146	22,922	32.0	929	5,770
1980	7	95	16.2	159	15,105	21.1	612	3,491
1979	8	19	3.2	181	3,439	4.8	139	698
1978	9	11	1.9	184	2,024	2.8	82	404
1977	10	12	2.0	191	2,292	3.2	93	441
1976	11	8	1.4	216	1,728	2.4	70	294
1975	12	1	0.2	169	169	0.2	7	37
1974	13+	0	0.0		0	0.0	0	0
	Total	586	100.0	122	71,586	100.0	2,900	21,536

Appendix A.3. Prince William Sound herring biomass distribution by age and year class, Stratum C, 1987.

Stratum C

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Biomass (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	11	0.6	49	540	0.5	11	200
1984	3	1,495	86.1	64	95,614	81.8	1,914	27,154
1983	4	138	7.9	75	10,350	8.9	207	2,507
1982	5	40	2.3	97	3,861	3.3	77	727
1981	6	39	2.2	119	4,634	4.0	93	708
1980	7	12	0.7	130	1,564	1.3	31	218
1979	8	1	0.1	150	150	0.1	3	18
1978	9	1	0.1	161	161	0.1	3	18
1977	10	0	0.0	0	0	0.0	0	0
1976	11	0	0.0	0	0	0.0	0	0
1975	12	0	0.0	0	0	0.0	0	0
1974	13+	0	0.0		0	0.0	0	0
	Total	1,737	100.0	67	116,874	100.0	2,340	31,550

Appendix A.4. Prince William Sound herring biomass distribution by age and year class, Stratum D, 1987.

Stratum D

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Biomass (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	2	0.3	58	116	0.2	17	262
1984	3	417	72.8	72	30,024	63.5	4,329	54,540
1983	4	62	10.8	86	5,332	11.3	769	8,109
1982	5	18	3.1	106	1,908	4.0	275	2,354
1981	6	36	6.3	125	4,500	9.5	649	4,708
1980	7	30	5.2	138	4,140	8.8	597	3,924
1979	8	4	0.7	150	600	1.3	87	523
1978	9	2	0.3	161	322	0.7	46	262
1977	10	1	0.2	220	220	0.5	32	131
1976	11	1	0.2	143	143	0.3	21	131
1975	12	0	0.0	0	0	0.0	0	0
1974	13+	0	0.0		0	0.0	0	0
	Total	573	100.0	83	47,305	100.0	6,820	74,943

Appendix B.1. Prince William Sound commercial purse seine harvest by age and year class, 1987.

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Harvest (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	1	0.1	73	73	0.0	1	18
1984	3	266	15.1	81	21,546	8.9	434	4,859
1983	4	139	7.9	106	14,734	6.1	297	2,539
1982	5	173	9.8	124	21,452	8.8	432	3,160
1981	6	570	32.3	144	82,080	33.8	1,653	10,413
1980	7	450	25.5	160	72,000	29.7	1,450	8,220
1979	8	60	3.4	169	10,140	4.2	204	1,096
1978	9	40	2.3	183	7,320	3.0	147	731
1977	10	39	2.2	193	7,527	3.1	152	712
1976	11	27	1.5	198	5,346	2.2	108	493
1975	12	2	0.1	213	426	0.2	9	37
1974	13+	0	0.0		0	0.0	0	0
	Total	1,767	100.0	137	242,644	100.0	4,886.0	32,279

Appendix B.2. Prince William Sound commercial gill net harvest by age and year class, 1987.

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Harvest (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	0	0.0	0	0	0.0	0	0
1984	3	0	0.0	0	0	0.0	0	0
1983	4	0	0.0	0	0	0.0	0	0
1982	5	18	2.6	150	2,700	2.4	13	80
1981	6	256	37.3	154	39,424	35.3	192	1,131
1980	7	212	30.9	160	33,920	30.4	165	936
1979	8	73	10.6	167	12,191	10.9	59	322
1978	9	37	5.4	175	6,475	5.8	32	163
1977	10	54	7.9	185	9,990	9.0	49	239
1976	11	29	4.2	192	5,568	5.0	27	128
1975	12	7	1.0	190	1,330	1.2	6	31
1974	13+	0	0.0	0	0	0.0	0	0
	Total	686	100.0	163	111,598	100.0	543.4	3,030

Appendix B.3. Prince William Sound commercial purse seine pound harvest by age and year class, 1987.

Year Class	Age Class	Number Sampled	% by Number	Mean Weight (g)	Weighting Factor (g)	% by Weight	Harvest (tons)	Number of Fish (* 1,000)
1986	1	0	0.0	0	0	0.0	0	0
1985	2	11	0.5	49	539	0.3	2	40
1984	3	1,685	72.5	65	109,525	57.8	436	6,078
1983	4	180	7.7	82	14,760	7.8	59	649
1982	5	91	3.9	111	10,101	5.3	40	328
1981	6	196	8.4	142	27,832	14.7	111	707
1980	7	107	4.6	157	16,799	8.9	67	386
1979	8	20	0.9	181	3,620	1.9	14	72
1978	9	12	0.5	184	2,208	1.2	9	43
1977	10	12	0.5	191	2,292	1.2	9	43
1976	11	8	0.3	216	1,728	0.9	7	29
1975	12	1	0.0	169	169	0.1	1	4
1974	13+	0	0.0	0	0	0.0	0	0
	Total	2,323	100.0	82	189,573	100.0	753.8	8,380

Appendix C.1. Prince William Sound 1988 herring projection biomass spreadsheet;
Natural Mortality at age 8 = 0.300;
1987 PWS total run biomass = 27,020 tons.

Age (t)	Mean Wt. at time t (g) [a]	Age Interval	G_t [b]	M_t [c]	$e^{(G-M)}$	$A_{(t)}$ [d]	$A_{(t+1)}/A_{(t)}$	$A_{(t+1)}/A_{(t)} \cdot e^{(G-M)}$
2	53.4	2-3	0.392	0.193	1.22		2.45 [e]	2.99
3	79.1	3-4	0.264	0.193	1.07	0.22	2.45	2.63
4	102.9	4-5	0.184	0.193	0.99	0.54	1.43	1.41
5	123.7	5-6	0.130	0.193	0.94	0.77	1.14	1.07
6	140.9	6-7	0.094	0.194	0.90	0.88	1.14	1.03
7	154.8	7-8	0.068	0.215	0.86	1.00	1.00	0.86
8	165.7	8-9	0.050	0.300	0.78	1.00	1.00	0.78
9	174.2	9-10	0.037	0.517	0.62	1.00	1.00	0.62
10	180.8	10-11	0.027	0.958	0.39	1.00	1.00	0.39
11	185.8	11-12	0.020	1.737	0.18	1.00	1.00	0.18
12	189.5	12-13	0.015	2.989	0.05	1.00	1.00	0.05
13	192.4	13-14	0.011	4.870	0.01	1.00	1.00	0.01
14	194.5							

1988 Projected Biomass

Age Class	1987 Escapement (tons)	1988 Projection (tons)	% by Weight	Number of fish(*1,000)	% by Number
2	26	0	0.0	0	0.0
3	7,101	79	0.2	909	0.4
4	1,721	18,710	58.1	164,889	66.8
5	1,520	2,430	7.6	17,827	7.2
6	4,858	1,632	5.1	10,506	4.3
7	3,833	4,995	15.5	29,273	11.9
8	785	3,310	10.3	18,118	7.3
9	364	612	1.9	3,184	1.3
10	356	225	0.7	1,130	0.5
11	255	140	0.4	686	0.3
12	18	46	0.1	219	0.1
13+	0	1	0.0	4	0.0
Total	20,837	32,180	100.0	246,745	100.0

a Weight at time t = 200.943 [1 - exp(-0.293(t+1.689))]$^{3.196}$.

b Instantaneous growth rate (G) = ln [$W_{(t+1)}/W_{(t)}$].

c Instantaneous natural mortality rate (M) schedule from Funk and Sandone (In press).

d Availability (A) schedule from Funk and Sandone (In press).

e Availability of age-2 herring unavailable. Therefore, A_3/A_2 was assumed to be at least equal to A_4/A_3.

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Appendix C.2. Prince William Sound 1988 herring projection biomass spreadsheet;
Natural Mortality at age 8 = 0.450
1987 PWS total run biomass = 27,020 tons.

Age (t)	Mean Wt. at time t (g) [a]	Age Interval	G_t [b]	M_t [c]	$e^{(G-M)}$	$A_{(t)}$ [d]	$A_{(t+1)}/A_{(t)}$	$A_{(t+1)}/A_{(t)} \cdot e^{(G-M)}$	Age Class	1987 Escapement (tons)	1988 Projection (tons)	% by Weight	Number of fish(*1,000)	% by Number
2	53.4	2-3	0.392	0.343	1.05		2.45^{e}	2.58	2	26	0	0.0	0	0.0
3	79.1	3-4	0.264	0.343	0.92	0.22	2.45	2.27	3	7,101	68	0.2	783	0.4
4	102.9	4-5	0.184	0.343	0.82	0.54	1.43	1.22	4	1,721	16,104	58.1	141,921	66.8
5	123.7	5-6	0.130	0.343	0.81	0.77	1.14	0.92	5	1,520	2,092	7.6	15,344	7.2
6	140.9	6-7	0.094	0.344	0.78	0.88	1.14	0.88	6	4,858	1,405	5.1	9,043	4.3
7	154.8	7-8	0.068	0.365	0.74	1.00	1.00	0.74	7	3,833	4,299	15.5	25,195	11.9
8	165.7	8-9	0.050	0.450	0.67	1.00	1.00	0.67	8	785	2,849	10.3	15,594	7.3
9	174.2	9-10	0.037	0.667	0.53	1.00	1.00	0.53	9	364	526	1.9	2,741	1.3
10	180.8	10-11	0.027	1.108	0.34	1.00	1.00	0.34	10	356	194	0.7	973	0.5
11	188.8	11-12	0.020	1.887	0.15	1.00	1.00	0.15	11	255	121	0.4	590	0.3
12	189.5	12-13	0.015	3.139	0.04	1.00	1.00	0.04	12	18	39	0.1	189	0.1
13	192.1	13-14	0.011	5.020	0.01	1.00	1.00	0.01	13	0	1	0.0	4	0.0
14	194.5													
Total										20,837	27,698	100.0	212,376	100.0

a Weight at time t = 200.943 [1 - exp(-0.293(t+1.689)]^{3.196} .

b Instantaneous growth rate (G) = ln [$W_{(t+1)}/W_{(t)}$].

c Instantaneous natural mortality rate (M) schedule from Funk and Sandone (In press).

d Availability (A) schedule from Funk and Sandone (In press).

e Availability of age-2 herring unavailable. Therefore, A_3/A_2 was assumed to be at least equal to A_4/A_3.

Appendix C.3. Prince William Sound 1988 herring projection biomass spreadsheet;
Natural Mortality at age 8 = 0.600
1987 PWS total run biomass = 27,020 tons.

| | | | | | | | | | | | 1988 Projected Biomass | | | |
Age (t)	Mean Wt. at time t (g)[a]	Age Interval	C_t[b]	M_t[c]	$e^{(G-M)}$	$A_{(t)}$[d]	$A_{(t+1)}/A_{(t)}$	$A_{(t+1)}/A_{(t)} \cdot e^{(G-M)}$	Age Class	1987 Escapement (tons)	1988 Projection (tons)	% by Weight	Number of fish (*1,000)	% by Number
2	53.4	2-3	0.392	0.493	0.90		2.45 [e]	2.22	2	26				
3	79.1	3-4	0.264	0.493	0.80	0.22	2.45	1.95	3	7,101	59	0.2	674	0.4
4	102.9	4-5	0.184	0.493	0.73	0.54	1.43	1.05	4	1,721	13,861	58.1	121,153	66.8
5	123.7	5-6	0.130	0.493	0.70	0.77	1.14	0.80	5	1,520	1,801	7.6	13,207	7.2
6	140.9	6-7	0.094	0.494	0.67	0.88	1.14	0.76	6	4,858	1,209	5.1	7,783	4.3
7	154.8	7-8	0.068	0.515	0.64	1.00	1.00	0.64	7	3,833	3,700	15.5	21,686	11.9
8	165.7	8-9	0.050	0.600	0.58	1.00	1.00	0.58	8	785	2,452	10.3	13,422	7.3
9	174.2	9-10	0.037	0.817	0.46	1.00	1.00	0.46	9	364	453	1.9	2,359	1.3
10	180.8	10-11	0.027	1.258	0.29	1.00	1.00	0.29	10	356	167	0.7	837	0.5
11	185.8	11-12	0.020	2.037	0.13	1.00	1.00	0.13	11	255	104	0.4	508	0.3
12	189.5	12-13	0.015	3.289	0.04	1.00	1.00	0.04	12	18	34	0.1	162	0.1
13	192.4	13-14	0.011	5.170	0.01	1.00	1.00	0.01	13	0	1	0.0	3	0.0
14	194.5													
									Total	20,837	23,840	100.0	182,793	100.0

[a] Weight at time t = 200.943 [1 - exp(-0.293(t+1.689)]$^{3.196}$.

[b] Instantaneous growth rate (G) = ln [W(t+1)/W(t)].

[c] Instantaneous natural mortality rate (M) schedule from Funk and Sandone (in press).

[d] Availability (A) schedule from Funk and Sandone (in press).

[e] Availability of age-2 herring unavailable. Therefore, A3/A2 was assumed to be at least equal to A4/A3.

Appendix C.4. Prince William Sound 1988 herring projection biomass spreadsheet;

Natural Mortality at age 8 = 0.300

1987 PWS total run biomass = 40,000 tons.

Age (t)	Mean Wt. at time t (g) [a]	Age Interval	G_t [b]	M_t [c]	$e^{(G-M)}$	$A_{(t)}$ [d]	$A_{(t+1)}/A_{(t)}$	$A_{(t+1)}/A_{(t)} \cdot e^{(G-M)}$	Age Class	1987 Escapement (tons)	1988 Projection (tons)	% by Weight	Number of fish (*1,000)	% by Number
2	53.4	2-3	0.392	0.193	1.22		2.45 [e]	2.99	2	41	0	0.0	0	0.0
3	79.9	3-4	0.264	0.193	1.07	0.22	2.45	2.63	3	10,930	122	0.2	1,406	0.4
4	102.9	4-5	0.184	0.193	0.99	0.54	1.43	1.41	7	2,718	28,799	56.3	253,799	65.2
5	123.7	5-6	0.130	0.193	0.94	0.77	1.14	1.07	5	2,484	3,839	7.5	28,160	7.2
6	140.9	6-7	0.094	0.194	0.90	0.88	1.14	1.03	6	8,131	2,666	5.2	17,165	4.4
7	154.8	7-8	0.068	0.215	0.86	1.00	1.00	0.86	7	6,482	8,360	16.4	48,995	12.6
8	165.7	8-9	0.050	0.300	0.78	1.00	1.00	0.78	8	1,296	5,598	11.0	30,640	7.9
9	174.2	9-10	0.037	0.517	0.62	1.00	1.00	0.62	9	629	1,009	2.0	5,255	1.4
10	180.8	10-11	0.027	0.958	0.39	1.00	1.00	0.39	10	628	389	0.8	1,953	0.5
11	185.8	11-12	0.020	1.737	0.18	1.00	1.00	0.18	11	445	248	0.5	1,209	0.3
11	189.5	12-13	0.015	2.989	0.05	1.00	1.00	0.05	12	34	80	0.2	383	0.4
12	192.4	13-14	0.011	4.870	0.01	1.00	1.00	0.01	13+	0	2	0.0	8	0.0
14	194.5													
									Total	33,817	51,112	100.0	388,970	100.0

a Weight at time t = 200.943 [1 - exp(-0.293(t+1.689)]$^{3.196}$.

b Instantaneous growth rate (G) = ln [$W_{(t+1)}/W_{(t)}$].

c Instantaneous natural mortality rate (M) schedule from Funk and Sandone (in press).

d Availability (A) schedule from Funk and Sandone (in press).

e Availability of age-2 herring unavailable. Therefore, A_3/A_2 was assumed to be at least equal to A_4/A_3.

1988 Projected Biomass

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Appendix C.5. Prince William Sound 1988 herring projection biomass spreadsheet;

Natural Mortality at age 8 = 0.450

1987 PWS total run biomass = 40,000 tons.

Age (t)	Mean Wt. at time t (g)[a]	Age Interval	G_t[b]	M_t[c]	$e^{(G-M)}$	$A_{(t)}$[d]	$A_{(t+1)}/A_{(t)}$	$A_{(t+1)}/A_{(t)}*e^{(G-M)}$	Age Class	1987 Escapement (tons)	1988 Projection (tons)	% by Weight	Number of fish(*1,000)	% by Number
2	53.4	2-3	0.392	0.343	1.05	0.22	2.45 [e]	2.58	2	41	0	0.0	0	0.0
3	79.1	3-4	0.264	0.343	0.92	0.54	2.45	2.27	3	10,930	105	0.2	1,210	0.4
4	102.9	4-5	0.184	0.343	0.85	0.77	1.43	1.22	4	2,718	24,787	56.3	218,445	65.2
5	123.7	5-6	0.130	0.343	0.81	0.88	1.14	0.92	5	2,484	3,304	7.5	24,127	7.2
6	140.9	6-7	0.094	0.344	0.78	1.00	1.14	0.88	6	8,131	2,295	5.2	14,774	4.4
7	154.8	7-8	0.068	0.365	0.74	1.00	1.00	0.74	7	6,482	7,195	16.4	42,170	12.6
8	165.7	8-9	0.050	0.450	0.67	1.00	1.00	0.67	8	1,296	4,818	11.0	23,372	7.9
9	174.2	9-10	0.037	0.667	0.53	1.00	1.00	0.53	9	629	869	2.0	4,523	1.4
10	180.8	10-11	0.027	1.108	0.34	1.00	1.00	0.34	10	628	335	0.8	1,681	0.5
11	185.8	11-12	0.020	1.887	0.15	1.00	1.00	0.15	11	445	213	0.5	1,040	0.3
12	189.5	12-13	0.015	3.139	0.04	1.00	1.00	0.04	12	34	69	0.2	329	0.1
13	192.4	13-14	0.011	5.020	0.01	1.00	1.00	0.01	13+	0	1	0.0	7	0.0
14	194.5													
									Total	33,817	43,992	100.0	334,789	100.0

1988 Projected Biomass

a Weight at time t = 200.943 [1 - exp(-0.293(t+1.689)]$^{3.196}$.

b Instantaneous growth rate (G) = ln [$W_{(t+1)}/W_{(t)}$].

c Instantaneous natural mortality rate (M) schedule from Funk and Sandone (In press).

d Availability (A) schedule from Funk and Sandone (In press).

e Availability of age-2 herring unavailable. Therefore, A_3/A_2 was assumed to be at least equal to A_4/A_3.

Appendix C.6. Prince William Sound 1988 herring projection biomass spreadsheet;
Natural Mortality at age 8 = 0.600
1987 PWS total run biomass = 40,000 tons.

Age (t)	Mean Wt. at time t (g) [a]	Age Interval	G_t [b]	M_t [c]	$e^{(G-M)}$	$A_{(t)}$ [d]	$A_{(t+1)}/A_{(t)}$	$A_{(t+1)}/A_{(t)}*e^{(G-M)}$
2	53.4	2-3	0.392	0.493	0.90	0.22	2.45 [e]	2.22
3	79.1	3-4	0.264	0.493	0.80	0.54	2.45	1.95
4	102.9	4-5	0.184	0.493	0.73	0.77	1.43	1.05
5	123.7	5-6	0.130	0.493	0.70	0.88	1.14	0.80
6	140.9	6-7	0.094	0.494	0.67	1.00	1.14	0.76
7	154.8	7-8	0.068	0.515	0.64	1.00	1.00	0.64
8	165.7	8-9	0.050	0.600	0.58	1.00	1.00	0.58
9	174.2	9-10	0.037	0.817	0.46	1.00	1.00	0.46
10	180.8	10-11	0.027	1.258	0.29	1.00	1.00	0.29
11	185.8	11-12	0.020	2.037	0.13	1.00	1.00	0.13
12	189.5	12-13	0.015	3.289	0.04	1.00	1.00	0.04
13	192.4	13-14	0.011	5.170	0.01	1.00	1.00	0.01
14	194.5							

1988 Projected Biomass

Age Class	1987 Escapement (tons)	1988 Projection (tons)	% by Weight	Number of fish(*1,000)	% by Number
2	41	0	0.0	0	0.0
3	10,939	91	0.2	1,041	0.4
4	2,718	21,335	56.3	188,018	65.2
5	2,484	2,844	7.5	20,861	7.2
6	8,131	1,975	5.2	12,716	4.4
7	6,482	6,193	16.4	36,266	12.6
8	1,296	4,147	11.0	22,699	7.9
9	629	748	2.0	6,893	1.4
10	628	288	0.8	1,447	0.5
11	445	183	0.5	896	0.3
12	34	59	0.2	284	0.1
13+	0	1	0.0	6	0.0
Total	33,817	37,864	100.0	288,156	100.0

[a] Weight at time t = $200.943 [1 - exp(-0.293(t+1.689)]^{3.196}$.

[b] Instantaneous growth rate (G) = $\ln (W_{(t+1)}/W_{(t)})$.

[c] Instantaneous natural mortality rate (M) schedule from Funk and Sandone (in press).

[d] Availability (A) schedule from Funk and Sandone (in press).

[e] Availability of age-2 herring unavailable. Therefore, A_3/A_2 was assumed to be at least equal to A_4/A_3.